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Optimizing Intralogistics in an Engineer-to-Order Enterprise with Job Shop Production: A Case Study of the Control Cabinet Manufacturing

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Abstract

This study underscores the benefits of refining the intralogistics process for small- to medium-sized manufacturing businesses (SMEs) in the engineer-to-order (ETO) sector, which relies heavily on manual tasks. Based on industrial visits and primary data from six SMEs, a new intralogistics concept and process was formulated. This approach enhances the value-added time of manufacturing workers while also facilitating complete digital integration as well as improving transparency and traceability. A practical application of this method in a company lead to cutting its lead time by roughly 11.3%. Additionally, improved oversight pinpointed excess inventory, resulting in advantages such as reduced capital needs and storage requirements. Anticipated future enhancements include better efficiency from more experienced warehouse staff and streamlined picking methods. Further, digital advancements hold promise for cost reductions in administrative and supportive roles.

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1. Introduction

While companies are driven to manufacture high-quality products, they simultaneously face the pressure of aligning with the distinct preferences of their customers [1]. This trend is particularly pronounced in engineer-to-order (ETO) strategies where the focus is on manufacturing products as per specific customer directives. Unlike traditional production strategies, ETO waits for a customer order before initiating the manufacturing process, which demands not only distinct designs but also unique material sourcing and specialized production processes. Such a bespoke approach inherently introduces numerous complexities. This surge in product variation echoes in various facets of production, from procurement and manufacturing to the pivotal aspect of material provisioning. Despite the burgeoning academic attention to the challenges of high-variance, low-volume manufacturing, there is a noticeable lack of research that address the unique constraints—whether financial or structural—of small- and medium-sized enterprises (SMEs). Additionally, the era of digital transformation in manufacturing can present multifarious benefits, from cost efficiencies and transparency to heightened customer alignment. Given the intensifying market competition, the transition to these digital tools is not just opportune but necessary [2]. This is especially true for SMEs, which are facing challenges such as local labor dependency and labor shortages while striving for customer satisfaction. An example is observed in the control cabinet manufacturing sector, which is characterized by batch-size-one and widespread reliance on paper-based documentation [1]. In the broader context of shifting market dynamics, the optimization of logistics activities is critical for securing a competitive edge. As digitalization continues to have a transformative impact, this study is designed to identify the latent savings and improvements that can be achieved by refining intralogistics processes within manual ETO job shop production.

Given these complex challenges and opportunities, this research seeks to explore the nuances of material provisioning in ETO manufacturing. The overarching research question guiding this investigation is: "*How can material provisioning in small or medium-sized enterprises with variant-rich production be optimized?*"

The article starts with developing a workflow based on process observations at six ETO SMEs as well as a literature view. The developed process is then implemented at an ETO company where it is validated by interviews, process observations as well as time recordings.

2. Literature Review

2.1. ETO Production Strategy

ETO is a production strategy particularly suitable for manufacturing highly customized, non-repetitive products, designed and manufactured in line with unique customer requirements. This approach is beneficial in environments demanding a high level of customization, where products are engineered from scratch or re-engineered based on existing designs [3]. The ETO strategy comprises two stages [4]. First, the non-physical stage encompasses tendering, engineering, design, and process planning activities. Second, the physical stage involves component manufacturing, assembly, and installation [5, 6, 7]. ETO supply chains are dynamic and complex, characterized by the order penetration point located at the design stage [7, 8].

The ETO-specific manufacturing system is entirely driven by customer orders, creating a high level of uncertainty in terms of product specification, supply and delivery lead times, and duration of the production processes [7]. In modern manufacturing, ETO companies are under growing pressure to lower lead times and costs while also delivering high levels of customization and flexibility. Achieving this balance is a significant challenge due to the inherent complexity and uncertainty of the ETO environment [9, 10].

2.2. Control Cabinet Manufacturing

Control cabinets are a cornerstone in key sectors of the manufacturing industry, spanning domains such as mechanical engineering, automotive, aerospace, and process industries. A characteristic feature of the control cabinet sector is its ETO production approach, necessitated by the tailor-made specifications of customer projects [11]. This is coupled with barriers in IT integration, often attributed to both limited capacity and a deficit in expertise to streamline processes throughout the value chain [12]. As described by [13], prevalent practices often showcase production that is predominantly workshop-oriented, with a low level of automation and insufficient IT integration. Adding to this is the sparse data availability. In nations where labor costs are exorbitant, creating customizable products on an individual scale demands innovative production strategies. A majority of control cabinet manufacturing still relies heavily on analog media [12]. Stepputat et al. [2, 14] addressed the data flow from design to assembly in control cabinet manufacturing, noting the transition from digital preparation in design to analog application in manufacturing. Further, there's a lack of insight into how this depicted information process could transform with digital media. Jagusch et al. [15] stressed the repercussions of the unavailability and inconsistency of information within control cabinet manufacturing. This scenario underscores the pressing need for a digital manufacturing process in control cabinet production, one that leverages a cohesive data foundation to ensure transparent information availability.

Digital assistance systems in assembly and wiring, as discussed in studies by Uttendorf and Kreutzjans [16] and Szajna et al. [14], often appear as stand-alone solutions, detached from the entire manufacturing process. Stepputat et al. [17] in their research alluded to the capability of storing documentation, which is then available to the ERP system, but there's no mention of the reciprocity of data flow, which is mirrored in experimental research on assistance systems for picking processes, where authors describe information outputs but don't delve into the data's origination and accessibility [18, 19].

2.3. Intralogistics

One area central to a company's efficiency and competitiveness is intralogistics [20]. Intralogistics encompasses the organization, control, execution, and optimization of internal material flow and accompanying information flow [21]. Core operational functions within logistics include transportation, handling, storage, and picking [22]. Picking lies at the core of warehouse logistics. It involves assembling goods from storage in particular quantities for designated orders. Typically, goods are stored in a picking warehouse in a sorted manner, and during the picking process, they are assembled as per the order. Due to the diverse shapes and sizes of items to be picked, automation can often be challenging [23]. There are two primary principles of picking: person-to-goods and goods-to-person [24]. In the person-to-goods method, the picker moves to the goods and retrieves the required items. Conversely, in the goods-to-person system, goods are automatically transported to the picker, who then selects the necessary items. While paper-based lists were commonly used for picking in the past, today there are numerous technical tools, such as pick-by-light, pick-by-voice, and pick-by-scan, which enhance efficiency and accuracy. The primary aim of these systems is to make the process more efficient, accurate, and user-friendly for the worker [25].

3. Methodology

3.1. Selection and Study of Enterprises

For this study, six enterprises were selected from the same industry, differing in their stages of digitalization and automation. These enterprises served as the foundational case studies, see Table 1.

Observing best practices within each company and integrating theoretical models from the literature facilitated the development of an optimal process. Following the conceptualization of this ideal process, a representative firm was chosen for a deeper investigation. The existing processes and efficiency of the intralogistics of this selected firm were thoroughly examined, allowing for a benchmark and baseline understanding. Subsequently, the previously designed optimal process was implemented within this firm. The objective was to assess the enhancements in efficiency using real-world data, compared to the established baseline.

TABLE 1 Overview of foundational cases for best practice evaluation.

Name	Company A	Company B	Company C
Turnover	2.9 mio €	18.5 mio €	10 mio €
Number of employees	10–20	100–150	100–150
Project scope	Only customer projects	Customer projects, internal use, and series production	Only internal use
Customer industries	Aviation, process, energy, automation, special machinery, food and beverage	Electrical engineering and automation	Electrical engineering and automation, special machinery
Name	**Company D**	**Company E**	**Company F**
Turnover	5 mio €	3.5 mio €	8 mio €
Number of employees	25–50	10–25	50–100
Project scope	Only customer projects	Customer projects and series production	Only customer projects
Customer industries	Aviation, process, energy, automation, special machinery, food and beverage	Special machinery	Electrical engineering and automation, Special machinery

3.2. Sources of Evidence in Process Design

During the phase of optimal process design, a combination of tools and methods was employed to capture a comprehensive set of data. Detailed video and photographic recordings of the processes were important in capturing real-time operations and activities. Concurrently, observation notes were taken to document intricacies and nuances via the use of a process canvas to structure the observed data. Interviews played a crucial role, with discussions held with managers, workshop leaders, and production workers to gain insights from diverse stakeholders. The resulting process flows and sub-processes were modeled in the BPMN standard and built the bases for the process design. Using a BPM approach for increasing production efficiency and process capacities has been successful in past studies like [26].

3.3. Evidence in the Validation Case

For the validation phase, a richer and more varied set of data was essential. An exhaustive evaluation of inventory and stock data from the past five years was conducted, providing a comprehensive view of material flow and usage patterns.

Time recordings of all processes over multiple days provided insight into efficiencies and potential bottlenecks. Furthermore, measurements of pathways in the storage areas and workshops provided data on mobility and layout efficiency. Lastly, an in-depth analysis of the design and manufacturing documentation for all projects produced over the previous five years gave insights into production trends and changes. Such a comprehensive approach to data collection ensured a rigorous and thorough comparison between the actual state and the state post-process alterations. This helped in solidifying the validation process, ensuring that conclusions were grounded in hard evidence. In summation, the methodology chosen permitted a deep and expansive exploration of the research question. The synthesis of exploratory qualitative methods with elements of descriptive and explanatory research, married with a focus on participant-driven data collection, forged a comprehensive examination of material provisioning optimization in SMEs with variant-rich production.

4. Process Design

4.1. Areas under Investigation

For the design of the optimal intralogistics process, it is pivotal to document the current state meticulously and in a coordinated manner. This documentation is crafted through an in-depth analysis of the prevailing situation, focusing especially on the routines of the personnel. *Layout of storage areas*: The objective of detailing the layout is twofold, to pinpoint potential vulnerabilities and provide a holistic overview of the storage areas. Following this, a rigorous recording is conducted, which documents the travel and search times of the employees, giving insights into the efficiency and possible points of delay in the current layout. *Processes and information flow*: Ensuring comprehensive documentation of all warehouse business processes by using the BPMN standard is employed. Alongside the recording of physical tasks, the flow of information and the utilization of documents are documented. Such an approach illuminates points of media discontinuity, which can impair performance when switching between different media such as digital systems and paper. *Determination of material stocks and unnecessary materials*: An analysis of the warehouse stocks facilitates the identification of both the material stocks and materials that are no longer required. This aids in maximizing available space and offers a comprehensive overview of the materials present in the workshop storage. *Past production volumes*: Evaluation of the manufacturing plans from previous years enabled the determination of production volume and the corresponding material requirements. From this, it became feasible to deduce the average time employees spent autonomously collecting the components. *Storage routes and search times*: To conduct a detailed assessment of the picking times, the travel and search durations of the employees were documented. Initially, the durations taken by the personnel to move from their workstations to the storage were measured. It's noteworthy that all employees have designated workstations where they can perform their tasks. The selected route adheres to occupational safety standards, representing the official path that should be taken by the employees to the storage.

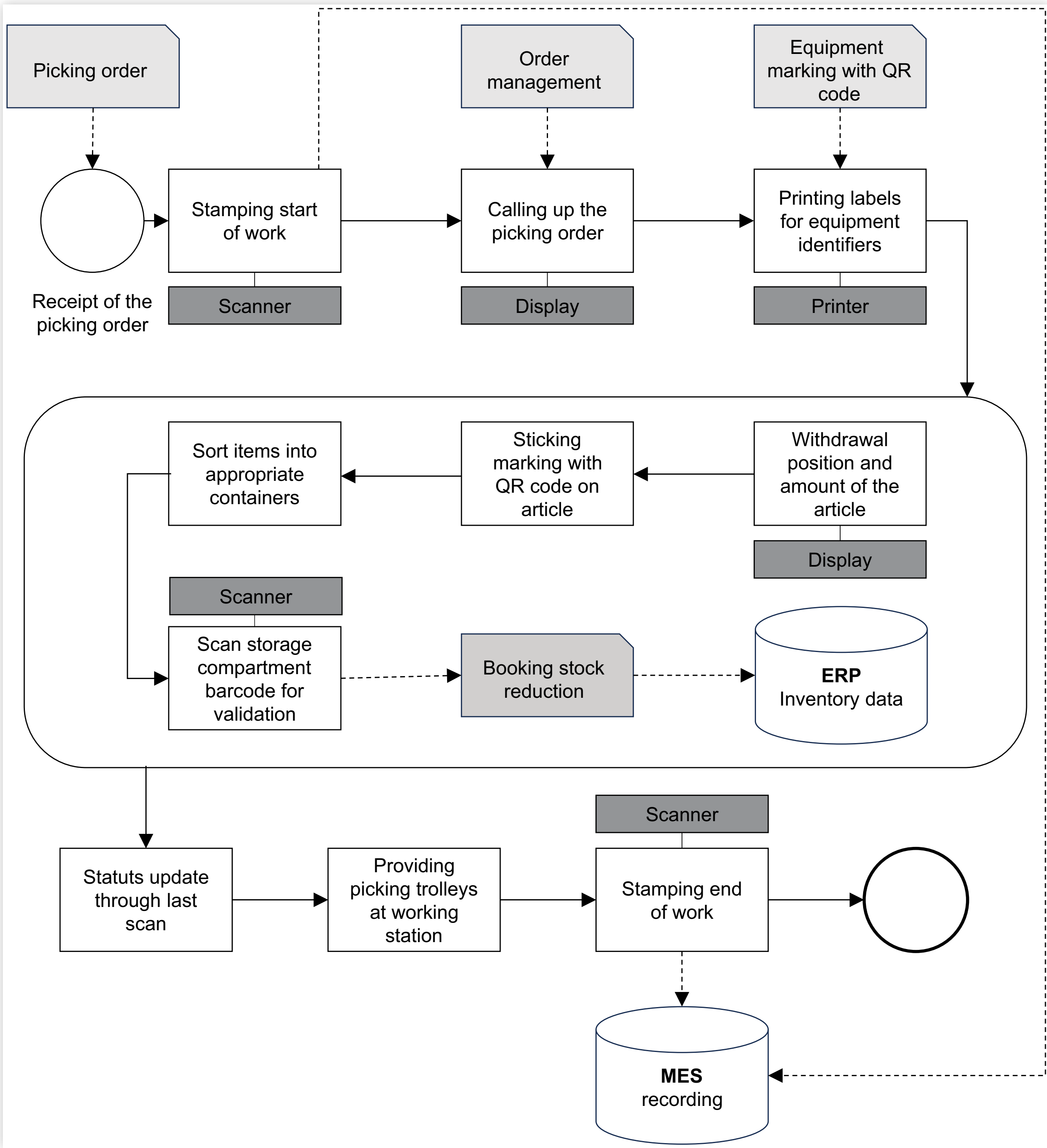
4.2. Process Description

From the construction data of past projects, patterns indicate which components are frequently used together. This intelligence aids in the optimal allocation of storage locations, placing frequently paired items adjacent to one another. During this assessment, any items identified as obsolete or no longer in use can be removed from inventory. Such an action not only enhances transparency but also reduces tied-up capital. While it's not possible to change the layout or position of the storage within the production area in the scope of this study—considering them as fixed parameters—the focus shifts toward the processes and information flow. The envisioned design for this workflow is depicted in Figure 1. A significant shift involves picking and material provision. Rather than the assembler, a dedicated warehouse worker equipped with a commissioning trolley will now handle the task.

Centralizing the commissioning trigger through the release of the production order increases transparency. As a further step to maximize the value-added time of the assembler, the responsibility of item marking for operational resources will be undertaken during commissioning. This approach ensures each item is distinctly identified and handled during this stage. The adoption of the pick-by-scan method aims to heighten both transparency and quality in material provisioning, especially in reducing the amount of incorrect parts being supplied. This is critical since many components appear similar, and the task can be performed by semi-skilled workers. An additional advantage of the pick-by-scan system is its precise data provision capability. The worker receives clear instructions about the type, quantity, and location of items to be picked. The system can also incorporate additional data, such as the most efficient path, potential errors, or relevant customer information. This not only improves productivity but also enhances customer satisfaction.

For machine-readable operational resource marking, a QR code is employed. QR codes are especially advantageous due to their impressive data density and minimal space requirements. They can encapsulate more than just identification numbers. This might include product descriptions, destinations, or even detailed instructions embedded directly in the code. Furthermore, the resilience of QR codes is evident in their in-built error correction. Even if a code is damaged or soiled, its structure often permits accurate scanning, a feature crucial for efficiency in bustling warehouse environments.

FIGURE 1 Target intralogistics process.



5. Case Study

5.1. Presentation of Validation Case

The enterprise under examination is a medium-sized entity employing 80–100 staff members and generating a turnover ranging between €10 and 20 million. The company's core competence is distinctly evident in its specialized portfolio, which features energy distributions and power systems. Furthermore, the company takes pride in its expertise in the design and fabrication of low-voltage switchgear and control cabinets. These include the creation of switch panels, busbar fields, and turbines. These systems are vital in providing consistent energy to residential complexes, other businesses, and various industrial facilities. The importance of ensuring an uninterrupted supply of energy dictates that the seamless operation of these systems is maintained perpetually. In addition to its manufacturing prowess, the company also commits significant resources to the planning and realization of digital solutions in areas such as smart process, smart maintenance, and smart energy at its main facility. However, for the scope of this study, the spotlight will primarily be on the company's workshop. This section of the business contributes to approximately 20% of the company's total turnover, focusing on the production of low-voltage switchgear and control cabinets.

5.2. Findings and Discussion

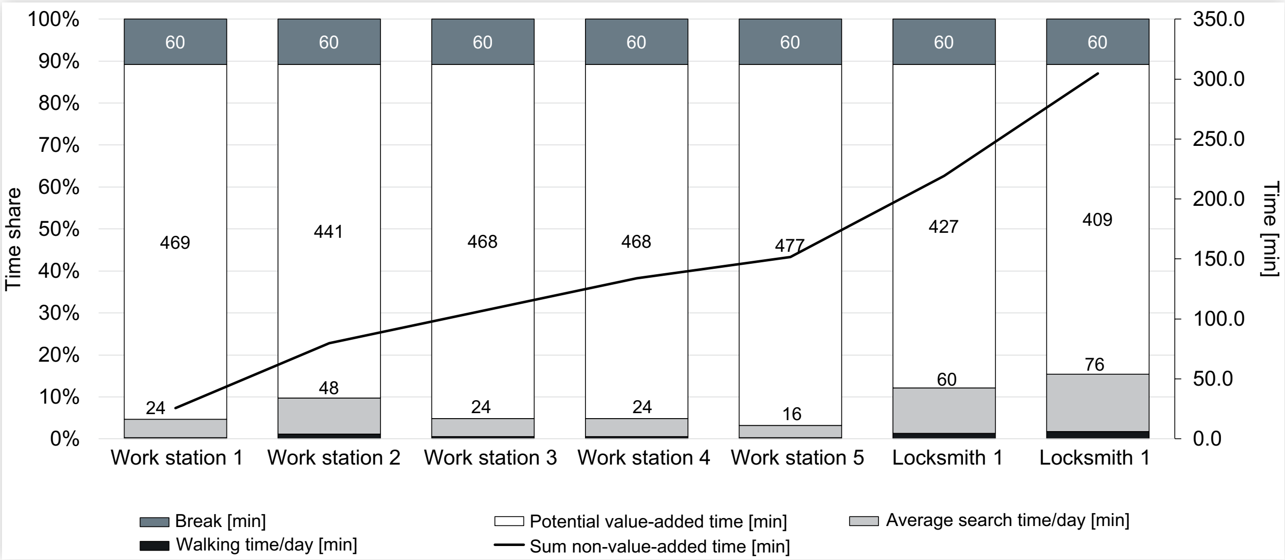
5.2.1. Impact on Inventory Management Components were ordered based on specific project needs. Minimum order quantities often led to the bulk purchasing of these components. Over time, these procurement practices resulted in the establishment of multiple storage areas, giving rise to complex and disorganized inventory structures characterized by a significant increase in stored materials. Compounding this challenge was the practice of reserving certain storage areas for specific project managers. These spaces became cluttered with materials previously procured for past projects and now remained as surplus. Labeled as project-specific materials, many of these components exceeded actual project needs. Moreover, each project manager had access only to their designated storage area, making it impossible to share or redistribute surplus materials between projects. The lack of shared knowledge led to duplicate orders. Further exacerbating the situation, items were neither systematically documented nor allocated to specific storage locations. The rented space for these untracked storage areas incurred an approximate monthly expense of €1,400, adding to the costs of capital tied up in the inventory itself. To address these challenges, rigorous steps were undertaken to streamline and optimize the inventory. An initial step was identifying items without usage. An in-depth assessment and analysis of the stored items helped discern which materials could be potentially discarded. For this purpose, the inventory lists of the last years were taken as the data basis for the analysis. Through this process, the inventory was refined, freeing up space for more relevant and frequently used items. The primary objective was to maintain an optimized inventory, retaining only pertinent and utilized components. Out of the evaluation, 113 items were dispensable, correlating with 76 different overarching material categories. These redundant items held a total inventory value of €30,725. For better understanding and organization, these materials were categorized into 51 primary groups. Concluding the analysis, production plans from 2017 to 2022 were assessed, offering invaluable insights for process enhancement. Since multiple individuals had contributed to these records, discrepancies across all documents were noticeable. Introducing the pick-by-scan method, as opposed to the earlier paper-based commissioning, addresses this issue by ensuring improved data consistency.

5.2.2. Layout and Storage Routes To gauge the frequency of warehouse visits by workers, a tally sheet was kept over two days. The data revealed that all employees, on average, spent around 32.7 minutes per day purely walking to the storage area. It was observed that warehouse visits occurred, on average, 34 times daily across all employees. Depending on the workstation, individual walking times between workspaces and the storage area ranged from 17.2 to 32.5 seconds. The primary aim is to reduce the average distance covered by a picker during their tasks. Different path-guiding strategies can be ideal depending on the structure of orders, placement strategies, and warehouse layout. One-dimensional movement is crucial in a person-to-goods system.

For the case in consideration, the dead-end aisle strategy, where repetition of the same aisle is avoided, proves suitable. This means the picker exits the aisle at the same point they entered. This method is apt for this case, particularly where shelves are positioned against walls, hindering alternative access unless a complete revamp of the shelf placement is considered. Ideally, the planned system should be designed such that each aisle is visited only once during a pick, and all items are retrieved in a systematic sequence. While there were no changes suggested for the existing layout, which means walking times to the warehouse remain unchanged, the introduction of the new path strategy combined with an organized pick list can potentially reduce the distances covered within the warehouse itself.

5.2.3. Value-Added Working Time For this analysis, average walking frequencies were determined over several days. Using the data from walking paths, the time spent walking per aisle was calculated. Multiplying the average search time of about 8 minutes in the warehouse with the number of aisle visits provided the total search time per day. Employees' work hours range from 06:30 to 15:45, accounting for a total break time of 1 hour. This results in an effective working time of 8.25 hours per day for each worker. To ascertain the poten-

FIGURE 2 Value-added working time less breaks, search times, and transit times.



tial value-added time, search and walking durations were subtracted, see Figure 2 and formula 1.

$$\text{Total working time} = t_{br} + t_s + t_w + t_{va} \qquad \text{Eq. (1)}$$

where

t_{br} is the break time
t_s is the search time
t_{va} is the value-added time
t_w is the walking time

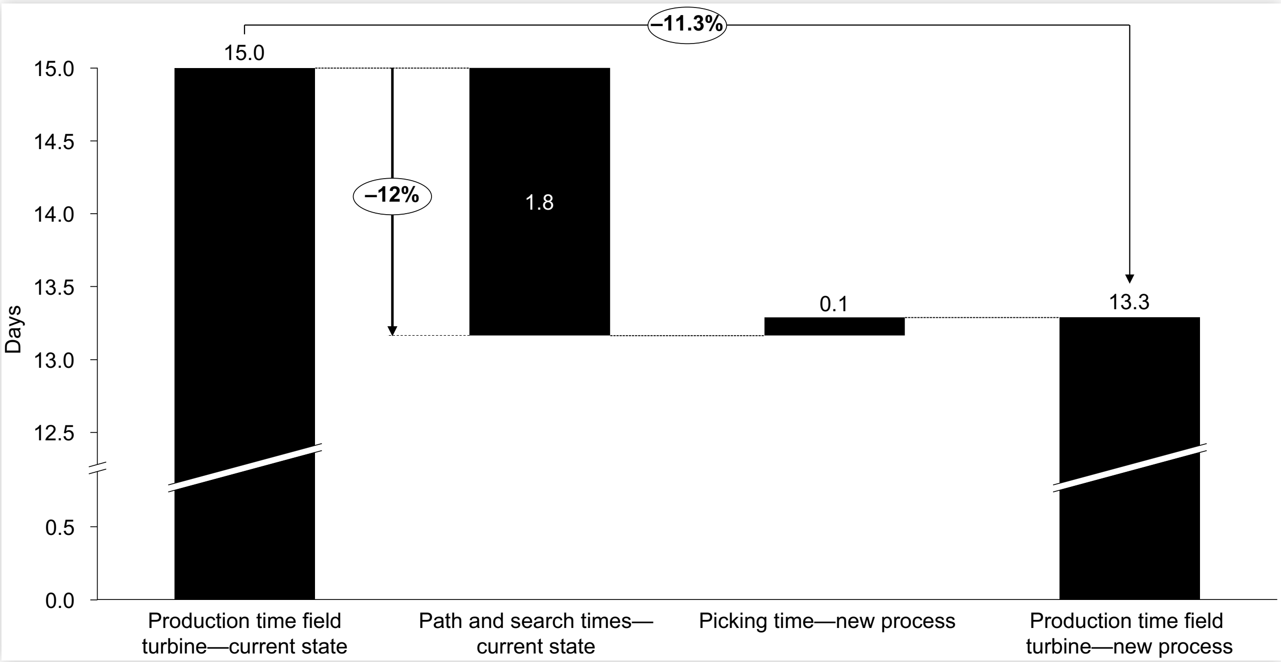
Due to the high material requirements of the locksmiths, they visit the workshop storage more frequently. This frequent visitation leads to a reduction in productive working time by 60 minutes daily. In the old process, material picking was carried out by the assembly technicians. Such an organizational approach led to significant time expenditures, translating to high costs. Furthermore, a paper-based picking method was in use. This meant that every time components were taken out, a time-consuming withdrawal slip had to be filled out. New employees and trainees, unfamiliar with the storage locations, often endured prolonged search and walking durations. In this process, they would frequently sift through multiple cabinets and shelves to locate the necessary items.

To highlight the potential time savings, a control cabinet was assembled using the new picking system and then compared to the previous system. For this, the warehouse worker was provided with a parts list and a picking cart. The product in question for the picking process is an 800 mm field turbine. Gathering the materials for the 800 mm field turbine took a total of 1:01:26.66 hours. The production time for such a control cabinet is 15 days. Typically, the assembly of this model is done by two team members. For illustration purposes, the average walking frequency of the four employees responsible for setting up the cabinet was calculated. Over a production duration of 15 days, this translates to four walking trips to the warehouse daily for each worker. This means that during this production phase, team members will visit the warehouse approximately 120 times. Additionally, an average search duration of 8 minutes per warehouse visit was considered. The proportion of time spent walking and searching during self-picking is on average 1.8 days. In the current picking process, this represents roughly 12% of the total production time during which no work on the project is conducted. After deducting the necessary tasks the worker performs at the workstation, such as receiving and independently picking up fastening materials, there's a potential to save about 11.3% of production time, see Figure 3.

6. Conclusion

This research has underscored the profound impact that streamlined inventory and operational processes can have on manufacturing efficiencies. One of the primary achievements has been the enhancement of data consistency and the bolstering of transparency. As a result, inventory levels have been effectively reduced, leading to both cost and space savings. One particularly salient benefit has been the strategy to combat the skilled worker shortage. By allowing semi-skilled workers to manage logistics, specialized personnel such as electronic technicians can focus more on core project activities. This not only optimizes their hours but also reduces the overall project costs. In our examined case of the turbine control, this reduction amounted to a notable 11.3% decrease in throughput time. Additionally, integrating these changes makes the manufacturing process more holistic and harmonized. This ensures that the process is more cohesive and adaptable to varying requirements. However, it's evident that there is still a need for more advanced control and planning systems and methods in

FIGURE 3 Value-added time, breaks, search, and transit times.



the ETO domain. Further research should focus on the long-term effects of these changes and should also include layout optimizations in the workshop as well as in the storage areas.

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